250kW 50 to 400HZ Motor-Generator Design Specifications for CMS Detector Electronics Power System rev.03Sep04wfj

1.0 This specification describes and defines the construction and performance requirements for a Motor-Generator set (MG) used to convert 50 Hz AC power to 400 Hz AC power to supply a 400 Hz load. Converter shall be a complete package including controls and safety systems.

1.1 The system supplier shall be a company that specializes in frequency conversion Motor-Generator sets and controls system design and that has been in business a minimum of 25 years. Supplier shall submit proof of prior experience in the design and application of frequency conversion systems and specified equipment. Manufacturer of the MG set shall have a quality program certified to ISO 9001:2000.

1.2 The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by the basic designation only:

ISO 281-1990: Bearing dynamic load ratings and rating life.

FEDERAL COMMUNICATION COMMISSION (FCC).
FCC, PART 18, CFR TITLE 47, Radio Frequency Interference Suppression.

MILITARY STANDARDS.
MIL-STD-704 (Rev. F) Aircraft Electric Power Characteristics.
MIL-STD-705 (Rev. C) Generator Sets, Engine Driven, Methods of Tests and Instructions

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION (NEMA).
NEMA 250 Type 1 Enclosures for electrical equipment.
NEMA MG 1 1998 (Rev. 1) Motors and Generators.

ISO 9001 Quality management systems

1.3 Environmental Conditions

The Motor-Generator set shall be capable of withstanding any combination of the following external environmental conditions without mechanical or electrical damage or degrading of operating characteristics:

1. An operating ambient temperature of -10°C to 40°C.
2. A non-operating and storage ambient temperature from -20°C to 55°C.
3. Relative humidity 0-95% non-condensing for temperatures stated in (1), not including condensation from temperature change.
2. Altitudes ranging from 0-1000 m (0-3300 feet).

1.4 Capability and Performance Requirements of Motor-Generator Set

A. Overload Capability: Satisfactory operating time is based on not more than one overload in 24 consecutive hours of operation.

Percent of Full Load	Satisfactory Operating Time
110 percent	2 hours
125 percent	5 minutes

B. Short Circuit: When a three-phase symmetrical short circuit is applied to the generator output, the generator shall be capable of sustaining at least 300 percent of rated current for not less than 10 seconds duration (with output circuit breaker disabled). A utility fed 300% short circuit boost circuit is required. Output circuit breaker shall be set to trip in less than 10 seconds at 300% rated current.

C. Radio Frequency Interference: FCC, PART 18, CFR TITLE 47

D. The Motor-Generator sets shall comply with the appropriate CE standards and carry a CE mark.

E. Voltage Characteristics: Initial voltage buildup shall be completely automatic. The output voltage shall be capable of being adjusted over a minimum range of plus or minus 10 percent from the rated voltage.

1. The steady-state limits shall be:
   a) Voltage regulation shall not exceed plus or minus 0.5 % from no load to full load.
   b) Drift shall not exceed plus or minus 0.5 percent over a 24-hour interval for an ambient temperature range of -10º C to 40º C.
   c) Voltage modulation shall not exceed 0.5 percent.

2. Transient Limits:
   The voltage deviation and recovery time with step load changes shall not exceed the following values given at rated power factor.

Transient (load step)	Voltage	Time
0% to 50%	-10%	0.20 seconds
0% to 100%	-20%	0.20 seconds
50% to 0%	+10%	0.20 seconds
100% to 0%	+20%	0.20 seconds

   Transient voltage and recovery on step load application to 95% of nominal voltage and step load removal to 105% of nominal voltage shall be within the time stated in the above table.

3. The Line-to-Neutral Phase-Voltage Unbalance:
   a) With a balanced load shall not exceed one percent between individual line voltages.
   b) With an unbalanced load of one-third rated current on one phase and no load on the other two phases, it shall not exceed 4 percent measured according to NEMA, defined as difference between maximum and minimum voltage divided by nominal voltage.

E. Waveform Characteristics:

1. With a balanced linear load:
   a) The total RMS voltage harmonics shall not exceed 3 percent of the fundamental voltage, measured line-to-line and line-to-neutral.
   b) The maximum single RMS line-to-neutral harmonic voltage shall not exceed 2 percent of the fundamental voltage.

2. With unbalanced load of one-third rated current on one phase and no load on the other two phases, total RMS harmonic shall not exceed 4 percent line-to-neutral. The deviation factor shall not exceed 0.1 per NEMA MG-1.

2.0 General Description

A. Input Voltage: 400 VAC +5%, -10%, 50 Hz 3-phase.

B. Output Voltage: 575 VAC, 400Hz +- 5%, 3-phase.

C. Output Rating: 250 kW (312.5 kVA). Minimum full load capacity at 0.8 lagging power factor.

D. The Motor-Generator set (MG set) shall consist of a single shaft rotor two bearing Motor-Generator assembly for 50 to 400 Hz conversion, with unit mounted controls and on a steel base. An automatic voltage regulator shall be provided with standard controls, protective devices necessary for control. The MG set shall have open drip proof construction, and the control panel shall be enclosed in accordance with NEMA 250, Type 1. The frame and enclosure shall be vermin proof. The Motor-Generator set and control panel shall be painted ANSI 61 gray.

1. The three phase, 50 Hz motor rated input shall have adequate horsepower to drive the generator at 120 percent of rated load.
2. All components shall be mounted on a common rigid steel base with the rotor assembly statically and dynamically balanced so as not to exceed a 0.001" double amplitude indicator reading.
3. Bearing Requirements: The bearings shall have a minimum calculated 100,000 hours of L-10 life as defined by ISO 281, when lubricated according to the schedule and with the type of lubricant specified in the operating manual. The bearings shall be equipped with grease fittings extended to the outer surface of the MG Set. Lubrication of the bearings shall not require a shutdown of the Motor-Generator set. It is required to be able to replace either bearing without removing the rotor from the stator assembly.
4. The Motor-Generator set shall be a brushless type; self ventilated, of drip-proof construction with windings that are impervious to oil, solvents, moisture, mild acids and alkalis. All terminals are to be identified on the wiring diagrams.
5. Insulation: The insulation of the motor and generator stators and fields shall be Class F or better, 100% vacuum pressure impregnated. The temperature rise will not be greater than 95° C above a 40° C ambient temperature. Asbestos insulation is prohibited. All materials are to be non-organic to prevent the support of fungus growth.
6. Exciter System: The exciter system shall be a brushless system utilizing individual exciters to supply the motor (if synchronous motor is used) and generator fields. Each exciter shall have separate shaft mounted, three-phase, silicon-diode bridge assemblies or be a permanent magnet generator type (PMG).
7. Dimensions: The size and weight of the Motor-Generator complete with unit-mounted controls shall be indicated in the manufacturer's quote.

E. The number of Motor-Generator sets required is 5 or 6 units.

F. Soft starters or reduced current / voltage starters on motors will be required. (i.e. series / parallel wye or wye-delta).

G. If a variable frequency drive (VFD) is used for the motor of the Motor-Generator set then a provision for bypass of the VFD is required. The motor of the MG set is required to be able to start and operate without the VFD unit.

H. Provision for remote voltage sensing or load current compensation is required on generator voltage regulator to compensate for IR drops between Motor-Generator and load. Phase compensation may be required because the load may be 150 meters away. If remote voltage sense is used the sense feedback signal shall be 230 VAC 400 Hz. If remote voltage sense is used the input to the voltage sense circuit shall be isolated from ground.

I. Ride through time of the generator for primary AC line sags is an important consideration in the selection of the Motor-Generator sets. Engineering practices such as the use of a flywheel and control/exciter power derived from generator output can be used to extend the ride through time of the generator.

1. A ride through time of 0.50 seconds at full load is required.
2. The manufacturer shall state in their quote what the expected ride through time is for their machines for a 10 % drop in output frequency at 100 % output load after the source of AC power to the motor is removed.
3. The MG motors shall not restart if a time interval of 0.25 seconds has passed since the 50 Hz power source has been removed. This time interval for non-restart shall be end user programmable.
4. It is required that all the MG sets be interlocked so that if one unit has entered into a non-restart mode during a power outage then the remaining MG sets also do **not** restart. This interlock can be a common signal bus that is passively pulled high and a trip or fault condition actively sinks this bus low.
5. An output signal in the form of 2 sets of dry contacts shall be provided when a MG set has entered a non-restart mode.
6. The manufacturer shall also state in their quote what is the maximum expected starting inrush current and duration of will be if, with the MG armature still spinning, the motor restarts with full load at 0.25 seconds elapsed time since the 50 Hz power source was removed.

J. The armature of the Motor-Generator set should be grounded through the use of slip rings and grounding brushes to protect the bearings.

K. Lifting Provisions: Two forklift openings meeting NEMA MG-1 requirements shall be provided on each side of the base. Each forklift opening shall be at least 20 cm wide and 12 cm high. Lifting eyes for overhead crane use is desirable.

2.1 Controls and Interlocks

A. Control Cabinet:

1. All controls, indicating lights, protective devices, monitoring systems and instruments shall be located within the control cabinet.
2. All wiring must have ample service loops and be protected from abrasion.
3. Wiring and wiring harnesses are to be secured at least every six inches.
4. All terminals are to be identified and shown on the wiring diagrams.
5. Control wiring will be separated from AC power wiring by a steel panel or the use of separate enclosures.

6. Fuses in accordance with industry standards shall protect the control circuit power.
7. The control cabinets shall use weather-stripping to minimize dust infiltration into the enclosure.

B. Input Circuit Breaker/Disconnect: An input circuit breaker of the 50 Hz power with under-voltage trip shall be provided. The input circuit breaker shall have a minimum interrupting capacity of 40,000 Amps RMS symmetrical.

C. Input Motor Controller: The motor shall be started and stopped by means of a reduced current / voltage motor controller equipped with overload protection. The field windings and rectifier assembly shall be protected against damage due to surges during starting or pulling out-of-step.

D. Output Circuit Breaker/Disconnect: An output circuit breaker of the 400 Hz power. An under-voltage trip shall be provided on the output circuit breaker if a 400Hz output contactor is not used.

E. Protective Controls: Relays, instrument transformers and circuitry on the generator's 400 Hz output necessary to provide protective control shall be provided. Protection to meet short circuit and overload requirement shall be provided. Protective circuits require operation of a reset button to allow output disconnect closing after a protective device opens the output disconnect.

F. Overvoltage: Shall protect by tripping the output circuit breaker for sustained overvoltage of 10 % or more above the nominal voltage, using a relay having an inverse-time characteristic. The overvoltage trip setting shall use load current compensation to automatically adjust the trip setting for the increase of output voltage of the generator for high load conditions.

G. Ground Fault detection on generator output is required. A remote readout of this signal can be part of **Section 2.1.2, A**.

H. A valid AC input power to Motor-Generator signal is required. All three phases of the 50 Hz power shall be monitored. This signal output shall indicate a fault no earlier than after one cycle of loss or under-voltage of the AC input power (0.020 seconds) and no later than three cycles (0.060 seconds). This is done to avoid false fault signals caused by sub-cycle dropouts. This monitoring device should have a trip setting adjustment range of 0 % to –25% of the nominal AC input voltage. This output signal is to be a fail-safe signal utilizing a dry contact output with 2 sets of dry contacts and **not** part of **Section 2.1.2, A.**

2.1.1 Operator Controls

All controls shall be heavy-duty industrial-type devices.

A. Manually Operated Controls: The manual controls can be traditional industrial controls or an industrial grade touch screen.
   1. All controls and readouts shall be clearly labeled.
   2. The use of the manually operated controls shall be intuitive and obvious for the casual operator and not require the use of a manual or special instructions.
   3. Set Control: Provide local "start" and "stop" pushbuttons to operate the motor controller.
   4. Provide "open" and "close" pushbuttons to operate the contactor, if used, which connects the generator to the 400 Hz load.
   5. Emergency Stop: A local emergency stop control on the MG controller front panel with a provision for an additional remote emergency stop is required. This item is required be a traditional industrial style control that is readily accessible, separate, and distinctive. The local emergency stop button shall be of a shielded or guarded type to prevent accidental activation of this function. The remote function shall use a normally closed contact for run condition and the contact shall open for stop (fail-safe). This emergency stop function shall immediately remove 400 Hz power from the output of the generator and the 50 Hz power source to the input of the motor. In addition to the emergency stop function a normal stop function is required to shut down the MG set by removing the 50 Hz input power to the motor and allowing the generator to spin down providing 400 Hz output power utilizing the ride through feature of the generator.
   6. A push-to-test button shall be included to simultaneously test all indicator lights.
   7. A reset pushbutton that must be actuated to restore normal operation after a monitored failure has occurred is required. The reset function will not override an interlock fault condition or cause an attempt to restore normal operation until the failure has been corrected.
   8. 400 Hz output circuit breaker: The operating handle for the generator circuit breaker shall be accessible from outside the enclosure. The external operating handle should have a provision for a lockout device.
   9. Voltage adjust: A readily accessible control which provides for setting the regulated generator voltage over the range of + and – 10 % of rated shall be provided.
   10. 50 Hz input circuit breaker: The operating handle for the input circuit breaker shall be accessible from outside the enclosure. The external operating handle should have a provision for a lockout device.
   11. Audible alarm: An "alarm silence" pushbutton shall be provided. Pressing this button shall silence the audible alarm and illuminate the "alarm silenced" indicator. Clearing of the fault, which initiated the alarm, shall return the alarm to the original state.

B. Visual Indications: Indicators shall be high-visibility LED's with an expected lifetime of not less than 60,000 hours.
   1. Motor on: Provide a green indicator that is illuminated when the motor controller is energized.
   2. Generator on: Provide a green indicator that is illuminated when the generator is at normal voltage.
   3. 400 Hz contactor closed: Provide a green indicator that is illuminated only when the generator-to-400 Hz load contactor is closed if 400Hz contactor is used.
   4. Motor failure: Provide a red indicator which is illuminated when the motor is overloaded or, if a synchronous motor is used, the field supply to the synchronous motor fails.
   5. Overvoltage: Provide a red indicator that is illuminated when the generator voltage exceeds the limits determined by the overvoltage protective relay.
   6. Undervoltage: Provide a red indicator that is illuminated when the generator voltage falls below the limits determined by the undervoltage protective relay.
   7. Generator overload: Provide a red indicator which is illuminated when the generator current exceeds the limit set by the generator overload sensing relay.
   8. Ground Fault: Provide a red indicator that is illuminated when a ground fault is detected on the output of the generator.
   9. A flashing beacon to indicate a machine fault. This indicator is to run in conjunction with the audible alarm of Item 2.1.1.A.11.
   10. Provide a red "alarm silenced" indicator.
   11. A run time meter shall be provided to record machine run time in hours. The run time meter shall be able to record time of $1(10^6)$-1 hours. If the meter is electronic then it should not use a battery for memory but store the time record in an internal EEPROM.
   12. An analog motor line ammeter to indicate the current in at least one phase of the motor, switchable to all three phases. Analog meters are to be 3.5 inches square, accurate to within two percent of the full-scale value.

2.1.2 Remote Data Readouts

A. Remote readouts of Motor-Generator status: The remote readout system is not required to provide local readouts of temperatures or of input voltage, input current and input power parameters. A local readout of output parameters is desirable. The following parameters should be monitored with a system such as a Nexus 1250 (with Ethernet TCP/IP protocol) or equivalent:

   1. Input 50 Hz Voltage, 3 phases
   2. Input 50 Hz Current, 3 phases
   3. Output 400 Hz Voltage, 3 phases
   4. Output 400 Hz Current, 3 phases
   5. Remote Sense Voltage or Remote Load Voltage, single phase

6. Output Power in Watts
7. Output power in VARs
8. Output Frequency
9. Generator Stator Temperature
10. Motor Stator Temperature
11. Additional Interlock and Machine status as needed.

B. The monitoring of both of the Motor-Generator set's bearings for a vibration analysis purpose with remote readout is required. All three axes of the bearings are to be monitored. Accelerometer configurations would be acceptable for monitoring purposes would be to monitor each bearing with an individual three-axis accelerometer or if single axis accelerometers are used then a horizontal and a vertical accelerometer for each bearing, with an additional common axial accelerometer per machine. This second method would require 5 accelerometers for each MG set. It is also suggested that the vibration analysis accelerometers be readout through the remote monitoring system of **Section 2.1.2, A**. Another alternative would be to use common bearing monitor system since all machines will be in close proximity of each other. A system such as Ludeca Vibronet (Pruftechnik) or equivalent can be used to monitor bearings

2.1.3 Other

A. Terminal Blocks: Suitable, clearly and permanently labeled terminal blocks which are readily accessible shall be provided in each separately mounted unit for the interconnecting wiring and for the power supply and load connections.

B. Wiring Identification: Both ends of all wiring are to be identified by means of an appropriate numbering system and shown on the matching wiring diagrams or schematics.

C. Ground Wire Color: The wires used for earth grounds will be color-coded green/yellow.

D. The use of Halogen Free wiring and materials in the construction of the Motor-Generator set is desirable. In event that halogenated materials are used the total amount must be less than 0.1 % of the total MG set weight. All efforts should be taken to avoid the use of halogenated material in free air (not enclosed).

E. Remote Indication Provisions: Terminals shall be provided for user's connection to a voltage-free normally open contact (2 sets) rated 120 V, 1 A, for remote summary alarm indication.

2.2 Testing of Motor-Generator Set

A. Fermilab engineering personnel shall witness factory testing and other quality control procedures of one or more of the Motor-Generators at a time that is mutually acceptable to Fermilab and the subcontractor.

B. Each Motor-Generator shall be tested in accordance with procedures based on MIL-STD-705 and IEEE Std 115 to verify the following parameters:

1. Insulation Resistance and Dielectric Strength
2. Winding Resistance
3. Generator open circuit voltage saturation
4. Voltage balance on windings
5. Current balance on windings
6. Voltage Transients and Recovery Time
7. Regulation with voltage regulator
8. Voltage adjustment range of voltage regulator
9. Phase sequence
10. Short Circuit Current (steady state) (Reference Item 1.4.B)
11. Efficiency
    a) At 50% load and rated power factor
    b) At 100%load and rated power factor
12. Vibration measurement
    a)At 0% load
    b)At 50% load.
    c)At 100% load
13. Harmonic measurements on the output
    a) At 0% load
    b) At 50% load and rated power factor
    c) At 100% load and rated power factor
14. Motor inrush current measurement (inrush current oscillograph data required)
    a) At cold start
    b) At 0.25 second restart after outage
15. Control function and metering test

C. The manufacturer shall measure and state in the test documents the noise level in dB's measured 1 meter away from the Motor-Generator set when running at full load.

D. If the Motor-Generator sets are a new and unproven design then a heat run test at 100% load at rated power factor will be required for the first unit.

E. The acceptance criteria for the Motor-Generators shall be the test results of standard tests plus any optional tests as agreed. A functional test shall be performed on the control panel and MG together to verify proper operation of Motor-Generator controls and metering devices.

F. Motor-Generator shall conform to NEMA MG-1 to the extent applicable.

G. The manufacturer shall provide copies of all test data and procedures used for testing of each Motor-Generator set at the time of shipment of the Motor-Generator set. The manufacturer shall also provide complete documentation and engineering drawings for each Motor-Generator set delivered plus two additional file copies. If a PLC or embedded digital controller is used in the MG sets then copies of the program(s) used shall be provided in both electronic and human readable (printout) forms.